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Trajectory patterns of technology fusion: Trend analysis and taxonomical grouping in nanobiotechnology

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ABSTRACT

The potential of technology fusion has been advanced as a promising breakthrough function to create hybrid technologies. Despite its importance, however, the evolutionary path of technology fusion is yet unexplored. In this paper, by employing the case of nanobiotechnology, we attempt to deepen understanding of the development trajectories of technology fusion in three important aspects. The first aspect is the development of an index that measures the degree of fusion of cross-disciplinary technology at the meso level. The second aspect is to classify the trajectory patterns of technology fusion in terms of fusion degree. We analyze fusion mechanism by utilizing citation network analysis. The third aspect is to visualize the relationship between patents and their backward and forward patent citations, at the patent class level, with their direction on a citation map. This facilitates understanding of the overview as well as fusion patterns. The changes in fusion patterns are analyzed using time series comparisons. An empirical analysis in the nanobiotechnology field shows no positive relationship between the inflow and outflow degree of fusion. We also observe changes in the trajectory patterns of fusion over time. Analysis demonstrates that each fusion pattern has evolved in such a way that technologies focus more on their niche technologies, and that those technologies which cannot incorporate the technology fusion have been eliminated during the development process.

1. Introduction

Amidst the ever faster pace of technological innovation, there have been a number of noteworthy changes in recent innovation trends. They are (a) the complexity of new products, (b) the miniaturization of new products, (c) the digitalization of products, and (d) the changes in architecture of products due to the appearance of new materials [1]. These changes emphasize the importance of the merging and overlapping of technologies [2]. Consequently, technological diversification such as technological convergence or technology fusion began to assume an important role in technology development across almost every industry in the past decade. With the increased interest in cross-disciplinary technologies, many activities that promote collaboration among different scientific and technological fields increased sharply in the anticipation that cross-disciplinary research would generate a higher rate of breakthroughs in recent years [3].

Moreover, techno-paradigm shifts [4] – from production companies to thinking (R&D) organization, from single business dynamics to multitechnologies base, from R&D activities against visible (within the same industry) competitors to invisible (in other industries) competitors, from linear (supply side) technology development to demand articulation process – have stimulated technology fusion even further. Despite the increasing interest in cross-disciplinary/interdisciplinary technology, the

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lack of data on cross-disciplinary/interdisciplinary research being a major impediment, relatively less research has been done on measuring interdisciplinarity with a few exceptions [5,6].

No one would argue that a proper understanding of the trajectory patterns of technology fusion is critical in making policies, decisions and plans in technology management. Researches in technological trajectories have been focused mostly on tracking emerging or key technologies [7–9], and many were limited to historical and descriptive analyses [9–11]. Although quantitative attempts have been made recently to trace trajectories [12–14], these quantitative methods were conducted at the levels of individual patent or sectoral discipline, or at the industrial level.

This paper introduces an index of fusion degree to measure the extent to which the precedent or following technology spreads across diverse technological fields at the meso level, i.e., technology patent class level. Based on the degree of fusion, the patterns of technology fusion mechanisms are defined. Subsequently, the technologies are grouped taxonomically into six patterns based on the inflow degree of fusion and outflow degree of fusion. The changes in fusion patterns over time are analyzed and compared. We develop a way to track the trajectory of technology fusion from its source technologies to its nozzle technologies, using both backward and forward patent citation. The trajectory is mapped with a citation network which shows the citation's direction as well. This visualized map displays an overview of the relationship between technologies and their sources or nozzles in relation to the fusion degree and number of sources or nozzles while it also represents conspicuous comparison between fusion patterns. We utilize both backward and forward patent citations in mapping and measuring the extent of technology fusion.

2. Background studies

2.1. Cross-disciplinary researches, taxonomy and citation network analysis

Long before Kodama [15] used the term ‘technology fusion’ to describe a type of innovation that leads to breakthrough functions by combining at least two or more existing technologies into hybrid technologies, technological convergence [16,17] and other terms such as technological diversification, interdisciplinary and cross-disciplinary technology have been used to describe similar phenomena [3,5,6]. Despite its attractiveness, the study of this phenomenon has been limited due to insufficient data on cross-disciplinary research. Although there are some debates on whether or not bibliometric tools are the most appropriate indicators [18], bibliometric tools have been used as the one of the most straightforward methods of assessing the extent of cross-disciplinarity since the 1980s [5,19,20].

Taxonomies have been widely applied to the studies of technological change, patterns of innovation and knowledge assets [21–24]. As taxonomies classify and name many different items into groups that share common traits, taxonomy can reduce the complexity of empirical phenomena to few and easy-to-remember categories [25]. Well-classified taxonomy of technological trajectories can be used as a predictive tool of the determinants of innovative performance [26].

Among other important virtues of patent citations such as an ability to trace multiple linkages among inventions, inventors, scientists, firms, locations, etc., an ability to trace spillovers and to create indicators of the importance of an individual patent has allowed patent citations to be used to trace the technological trajectories [27]. As citations provide good evidence on links between innovations and their technological ‘antecedents’ and ‘descendants’ [28], they have increasingly become one of the main indicators of the technological relationships among inventions. Numerous studies utilize citations to measure knowledge flows between technologies, technology trends, and so forth [29,30]. Backward citation is used to measure the inflow knowledge from other technologies while forward citation is used to measure the inventive quality in terms of technological and/or economic values [28,31,32]. These unique linking properties of citation provide useful information on what is vital in studying technology fusion, which is greatly influenced by relationships among other technologies. Porter et al. [5] establish an indicator of cross-disciplinary research with citations and references by using journal citation data. There are many other researches using citations to study the diffusion of technological information and to measure technological quality and its influence [33].

Using patent citations in network analysis, individual patents are represented by nodes, and citations among patents are denoted as edges which refer to interactions among nodes [34]. Citation network analysis has been developed starting from a mere counting of the number of citations to more sophisticated methods, such as using weights on citations. The citation network analysis, which is weighted by citation links, is utilized to map technological trajectories and track emerging technologies [7,12,13,35].

3. Methods

3.1. Research framework

To overview the big picture of the technology development trajectory of technology fusion, the development path is examined with patent citation information at the patent class level since bibliometric indicators based on citations and references more accurately capture the generation of cross-disciplinary knowledge than do approaches tracking co-authors' disciplinary affiliations [3]. Although there are many researches on patent citation networks, most of them use a frequency of citations that technology patent received or cited individual patent itself. We use the occurrence frequency of citation classes among patent classes, on which no previous studies have been done at this level, to the best of the authors' knowledge.

To classify the development patterns of technology fusion, technology trajectories are mapped by using a patent citation network. Backward citations, which reflect the influence of prior art on a particular technology, are used to track past trajectories;